

Section 6.4 DEVELOPMENT OF AIR CONDITIONING EMISSION FACTORS

This section discusses the correction factors used to scale down emissions for air conditioner operation over a range of ambient conditions. This methodology takes into account the compressor activity, relative humidity, heat index, and fraction of vehicles with functioning air conditioning (A/C) systems.

6.4.1 Introduction

The effects of A/C are not accounted for in MVEI7G. Recent tests have shown that A/C usage can have a significant impact on vehicle emissions. Currently, a vehicle that undergoes an emissions test receives an extra 10 percent load to the road load horsepower if that vehicle is equipped with A/C. Nearly all available data on A/C effects have been collected over the Federal Test Procedure (FTP) and SC03 driving cycles, however, the Unified Cycle (UC) is more representative of current driving patterns and will be the base emissions test cycle used in EMFAC2000. The correction factors, when scaled down over the range of ambient conditions to represent partial A/C load, will more accurately represent the impact of A/C on emissions. These adjustment factors will be applied to emissions data for the fraction of the fleet with A/C_{on}. The fraction of the fleet with A/C_{on} is a function of a heat index based on the combined impact of temperature and humidity. Estimates will be provided for the fraction of vehicles equipped with A/C systems, and of those, the fraction of malfunctioning systems. This memorandum will be segregated into two major components: emissions and A/C activity.

6.4.2 Emissions

Vehicle testing was conducted on 10 vehicles (Appendix 6.4-A) at 75 degrees on the UC. The tests were conducted with the A/C_{off} but with an added 10 percent road load horsepower (RLHP) and with the A/C_{on} but without the 10 percent RLHP added. Analysis of the data shows that the emissions collected with the A/C_{on} are significantly higher than would be estimated with the 10 percent adjustment assumed in the MVEI7G model. The mean emissions with the extra 10 percent RLHP added and with the A/C_{on} are shown in Table 6.4-1. The following regression equation was used to model each pollutant for Bag 2 emissions as a function of A/C_{off} with RLHP:

$$A/C_{on} = m * (A/C_{10\%}) + C \quad (6.4-1)$$

Since the historical UC data have been collected with A/C_{10%}, this equation becomes:

$$A/C_{on} = m * (UC_{bag2}) + C \quad (6.4-2)$$

Table 6.4-2 lists the coefficients for m and C. The emissions data and regression lines are shown in Figures 6.4-1 through 6.4-4.

Table 6.4-1. Mean Emissions.

	with 10% RLHP	with A/C _{on}
HC	0.045	0.051
CO	1.518	2.374
CO ₂	391.394	430.017
NO _x	0.405	0.511

Table 6.4-2. Coefficients for Adjustment.

	m	C	R ²
HC	1.226	0	0.894
CO	1.511	0	0.753
CO ₂	0.805	116.769	0.573
NO _x	1.198	0	0.820

6.4.3 A/C Activity Factors

Since "full-usage" A/C correction factors represent the emission increase during full load on the engine attributable to the A/C system, these factors must be scaled down to reflect the ambient conditions under which the model is run. The emissions factor equation should be adjusted to:

$$A/C_{adj} = (A/C_{10\%}) * [1 - A/C_{on}] + (A/C) * [A/C_{on}], \quad (6.4-3)$$

where

$$[A/C_{on}] = [\text{fraction equipped with A/C}] * [\text{fraction of functional A/C systems}] * [\text{compressor activity fraction algorithm}] \quad (6.4-4)$$

6.4.3.1 Compressor Activity Fraction

Compressor Activity

EMFAC2000 will correlate emissions with the operation of the vehicle's A/C compressor

since it is the direct cause of the additional load on the engine. To model intermediate conditions which result in partial A/C load, EMFAC2000 will include a factor to model compressor time as a function of the heat index based on temperature and humidity. This correction factor will characterize overall A/C system load by reflecting the percentage of time that the compressor is actually engaged. The proposed approach will scale down the full-use emission factor by using compressor time as well as using the heat index. The compressor on fraction (COM_{fr}) may be represented as:

$$COM_{fr} = K + a*HI + b*HI^2, \quad (6.4-5)$$

where a and b are coefficients for the heat index, and K is a constant. The scaling, or demand factor, coefficients provided by U.S. EPA for "all combined" periods of the day are shown in Table 6.4-3. Figure 6.4-5 illustrates the relationship between heat index and compressor fraction.

Table 6.4-3. Demand Factor Equation Coefficients.

Period	Constant(K)	a	b	R ²
All Combined	-3.631541	0.072465	-0.000276	0.44

Relative Humidity

Temperature and relative humidity have a significant impact on the engine load placed on the A/C system. They influence the amount of A/C usage in a vehicle. These two factors comprise the heat index and quantify the driver discomfort caused by their combined effects. Temperature matrices in which county-specific monthly, in addition to O₃- and CO-episode day, diurnal temperature profiles were developed. A sample matrix is provided in Table 6.4-4. Similarly, relative humidity matrices have been created for each county to profile average monthly humidity readings.

Heat Index

U.S. EPA has provided heat index values. The temperatures range from 50 to 100 degrees in 5 degree increments, and the relative humidity is from 0 to 100 percent in 10 percent intervals. The heat index numbers in Table 6.4-5 were used to model heat index as a function of temperature and humidity. Figure 6.4-6 illustrates the relationship between temperature, humidity, and heat index.

Table 6.4-4. Format of County-Specific Humidity Matrix.

County ID	County	Period	Hour						
			H0	H1	H2	H21	H22	H23
1	Alameda	January							
1	Alameda	February							
1	Alameda	March							
1	Alameda	April							
1	Alameda	May							
1	Alameda	June							
1	Alameda	July							
1	Alameda	August							
1	Alameda	September							
1	Alameda	October							
1	Alameda	November							
1	Alameda	December							
1	Alameda	annual avg							
1	Alameda	ozone							
1	Alameda	co							
2	Alpine	January							
:									
:									
58	Yolo	ozone							
58	Yolo	co							

Table 6.4-5. Heat Index Values.

	0% RH	10% RH	20% RH	30% RH	40% RH	50% RH	60% RH	70% RH	80% RH	90% RH	100% RH
50°	41	41	42	43	43	44	45	46	46	47	48
55°	46	47	48	49	49	50	51	52	53	53	54
60°	51	52	53	54	55	56	57	58	59	60	60
65°	57	58	59	60	61	62	63	64	65	66	67
70°	63	64	65	66	68	69	69	70	71	72	73
75°	69	70	72	73	74	74	75	76	77	78	78
80°	76	77	78	79	79	80	82	83	84	86	89
85°	80	81	82	84	85	87	89	92	95	100	106
90°	84	86	87	89	92	95	99	104	112	125	148
95°	88	90	92	96	100	105	113	125	146	166	166
100°	92	95	98	103	109	119	135	158	166	166	166

6.4.3.2 Fraction of Vehicles Equipped with A/C

To determine the fraction of vehicles in the fleet that are equipped with A/C systems, EPA has estimated base market penetration rates by model year using Ward's Automotive Handbook for light-duty automobiles. The projection cap was 98% of vehicles and 95% of trucks would likely be equipped with A/C by the 1999 model year (Table 6.4-6).

6.4.3.3 Fraction of Functional A/C Systems

Using the annual Consumers Reports Automobile Purchase issue which surveys readers on A/C system malfunctions by vehicle age, the U.S. EPA estimates yearly increases in the absolute malfunction rate of 1.5 percent, and starting at age nine the rate is held constant at 12.5 percent. To estimate the rate of repair, the following assumptions were used: 1) all vehicles up to three years old (the standard warranty period) would be repaired; 2) after three years the majority of vehicles would still be repaired, but this percentage decreases as the vehicle becomes older; and c) vehicles before the 1993 model year (estimated cutpoint for R-134a Freon replacement on most vehicles) would have a lower rate of repair due to the cost of system recharging. The U.S. EPA estimated that 100% of the R-134a systems would be repaired during the 3-year warranty period, 90% in years four through eight, 80% in years nine through 13, 70% in years 14 through 18 and 60% in years 19 and up. The non-warranty period repair rate is reduced by a factor of 0.75 for pre-1993 system if the modeled calendar year is 1995 or later. Table 6.4-7 summarizes the malfunction rates. Therefore, the estimate of vehicles with functional A/C systems combines the base market penetration rates for that model year with the unrepaired malfunction rates for the appropriate vehicle age. Table 6.4-8 shows a sample calculation using the correction factor.

Table 6.4-6. Proposed Base Market Penetration Rates.

Model Yr	% LDVs equipped with A/C	% LDTs equipped with A/C
72	60	29
73	73	29
74	62	29
75	63	29
76	68	31
77	73	36
78	72	38
79	70	36
80	63	35
81	67	39
82	70	45
83	74	47
84	78	53
85	80	54
86	79	55
87	76	60
88	79	65
89	78	74
90	87	77

91	87	78
92	89	82
93	91	84
94	93	86
95	94	89
96	95	91
97	97	93
98	98	95
99	98	95
00+	98	95

Table 6.4-7. Proposed Rate of A/C Malfunction.

Vehicle Age (years)	Consumer Reports*	Proposed Estimates
1	< 2%	0.5 %
2	2 - 5 %	2.0 %
3	2 - 5 %	3.5 %
4	2 - 5 %	5.0 %
5	5 - 9.3 %	6.5 %
6	5 - 9.3 %	8.0 %
7	9.3 - 14.8 %	9.5 %
8	9.3 - 14.8 %	11.0 %
9+	n/a	12.5 %

* 1997 Automobile Purchase Issue

Table 6.4-8. Sample Calculation Using ACCF.

Pollutant	A/C _{10%} (g/mi)	Emission Rates (g/mi)
ROG	0.287	0.334
CO	5.131	7.019
NO_x	0.740	0.761
CO₂	308.777	349.498

*Calendar year 1998, South Coast; assuming compressor is always on, percent of fleet equipped with A/C is 90, and fraction of functional systems is 0.8

FIGURE 6.4-1

COMPARISON OF HC EMISSIONS WITH 10% RLHP TO AC_{ON} FOR UC CYCLE

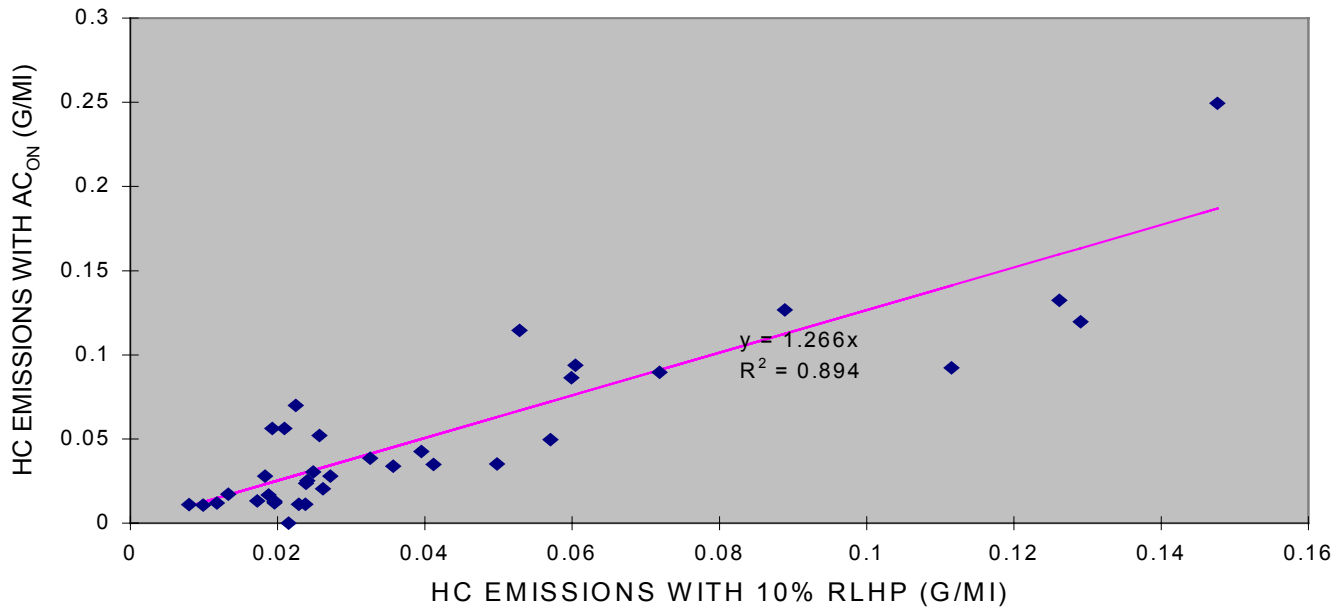


FIGURE 6.4-2

COMPARISON OF CO EMISSIONS WITH 10% RLHP TO AC_{ON} FOR UC CYCLE

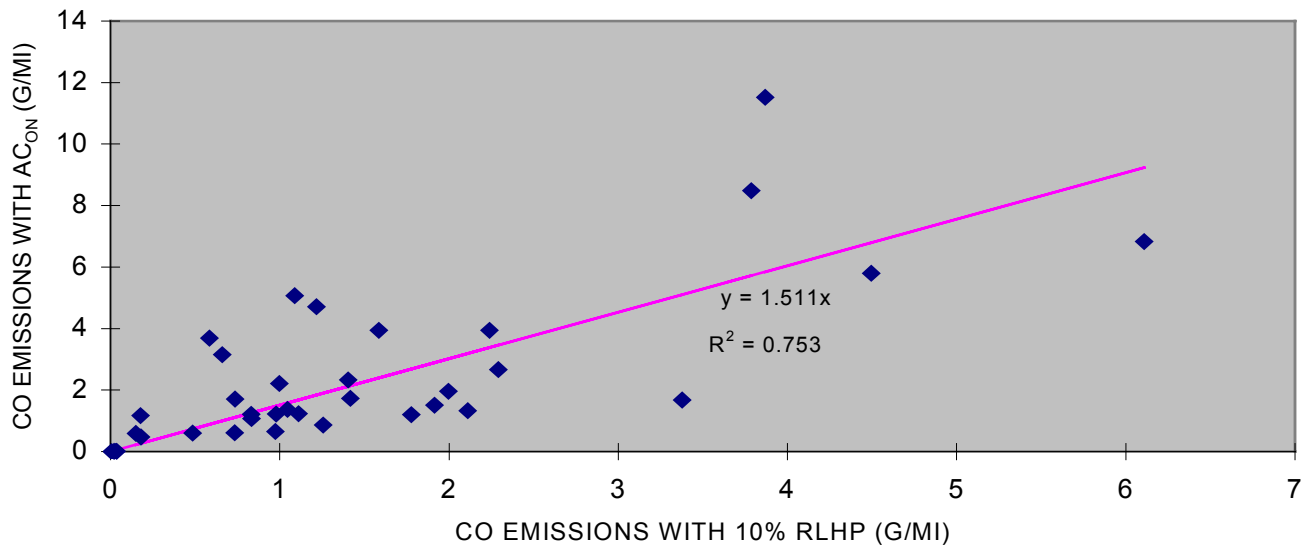


FIGURE 6.4-3

COMPARISON OF CO₂ EMISSIONS WITH 10% RLHP TO AC_{ON} FOR UC CYCLE

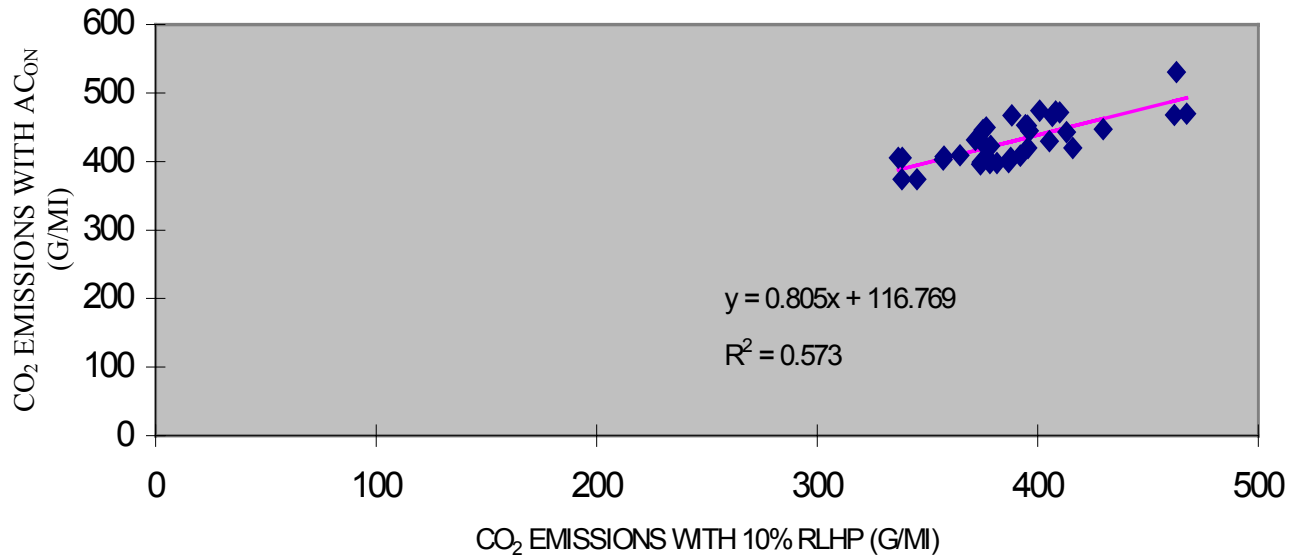


FIGURE 6.4-4

COMPARISON OF NO_x EMISSIONS WITH 10% RLHP TO AC_{ON} FOR UC CYCLE

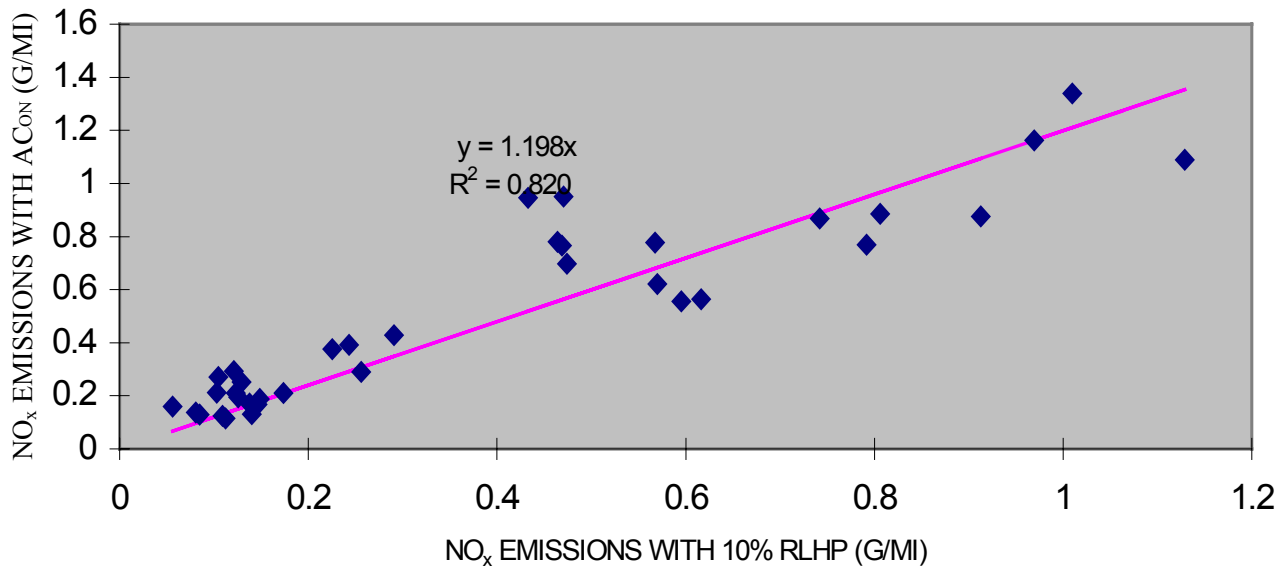


FIGURE 6.4-5
Compressor Fraction vs Heat Index

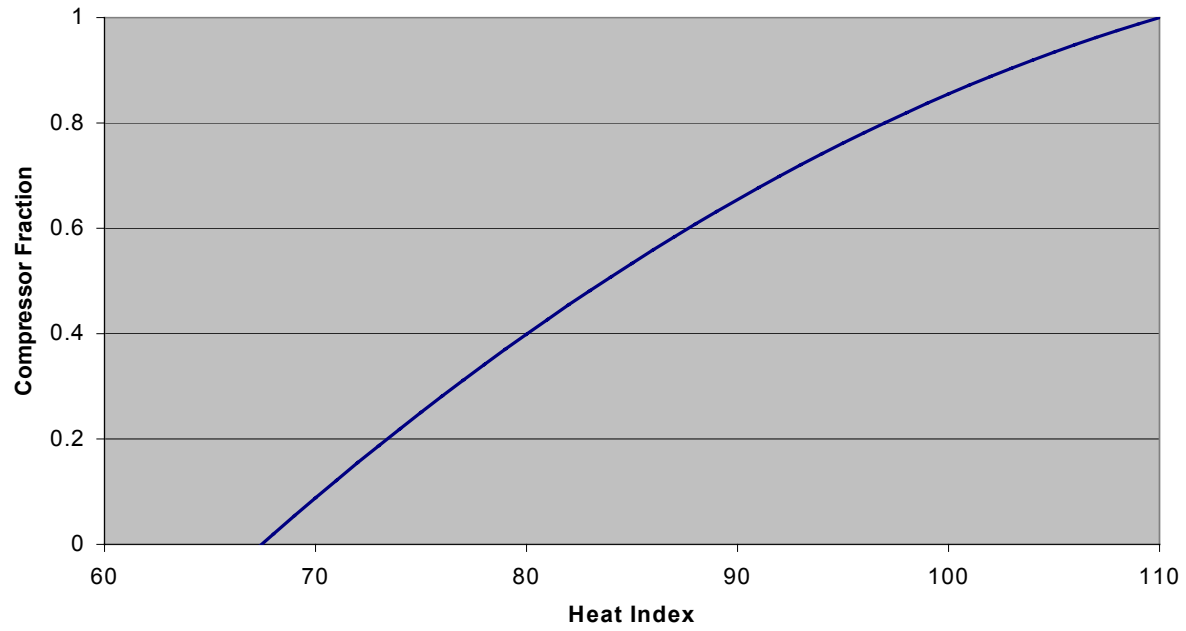
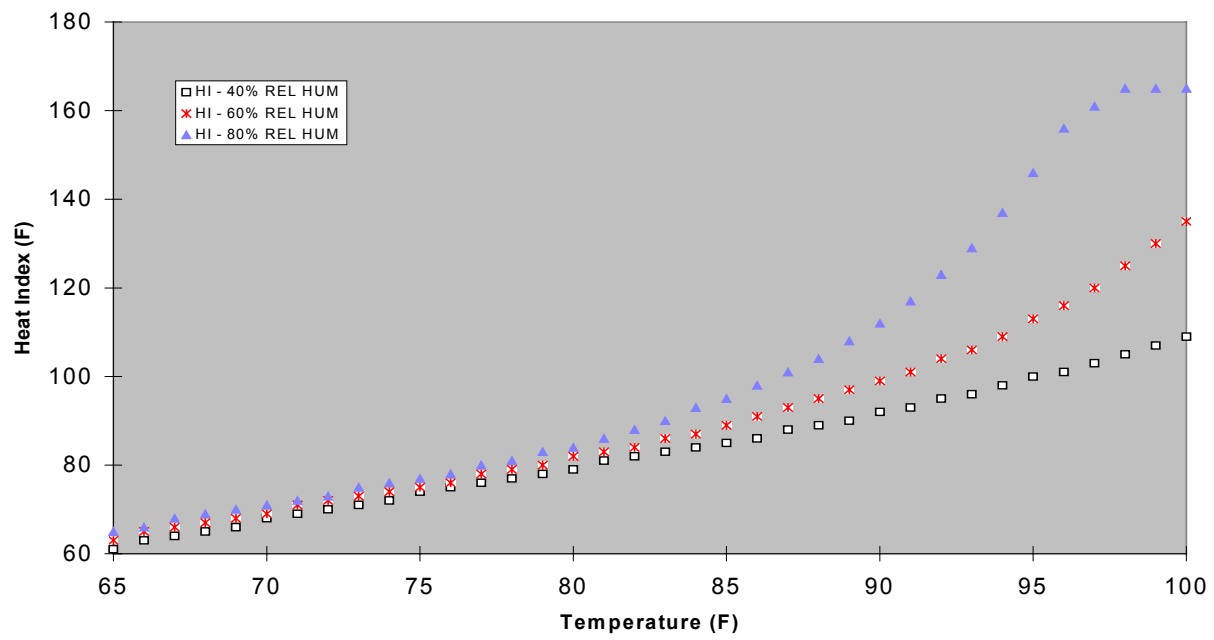


FIGURE 6.4-6
Heat Index



Appendix 6.4-A. Description of Test Vehicles.

Model Year	Manufacturer	Division	Model
91	GM	Chevrolet	Lumina
91	Ford	Ford	Taurus
92	GM	Chevrolet	Astrovan
92	Ford	Ford	Tempo
94	Ford	Ford	Taurus
96	Honda	Honda	Accord
94	Ford	Ford	Taurus
92	GM	Pontiac	Grand Am
95	GM	Oldsmobile	Cutlass
97	GM	Oldsmobile	Achieva